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Comparison of Fragmentation Functions for Jets Dominated by Light Quarks and Gluons from pp and Pb + Pb Collisions in ATLAS

M. Aaboud *et al.**
(ATLAS Collaboration)

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Charged-particle fragmentation functions for jets azimuthally balanced by a high-transverse-momentum, prompt, isolated photon are measured in 25 pb^{-1} of pp and 0.49 nb^{-1} of Pb + Pb collision data at 5.02 TeV per nucleon pair recorded with the ATLAS detector at the Large Hadron Collider. The measurements are compared to predictions of Monte Carlo generators and to measurements of inclusively selected jets. In pp collisions, a different jet fragmentation function in photon-tagged events from that in inclusive jet events arises from the difference in fragmentation between light quarks and gluons. The ratios of the fragmentation functions in Pb + Pb events to that in pp events are used to explore the parton color-charge dependence of jet quenching in the hot medium. In relatively peripheral collisions, fragmentation functions exhibit a similar modification pattern for photon-tagged and inclusive jets. However, photon-tagged jets are observed to have larger modifications than inclusive jets in central Pb + Pb events.

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Ultrarelativistic nucleus-nucleus collisions create a quark-gluon plasma, a hot, dense, and long-lived system of deconfined quarks and gluons. The high density of unscreened color charges causes hard-scattered partons with large transverse momentum (p_T) to lose energy as they traverse the medium, a phenomenon referred to as jet quenching. In lead-lead (Pb + Pb) collisions at the Large Hadron Collider (LHC), jet production rates at fixed p_T are suppressed relative to proton-proton (pp) collisions [1–4]. Since the parton shower develops inside the quark-gluon plasma, the momentum distributions of hadrons in the quenched jet are also modified. Measurements of the jet fragmentation function (FF) for inclusively produced jets in Pb + Pb collisions [5–7] exhibit differences from pp collisions. In these measurements, jets are selected by their final-state p_T, i.e., after the effects of quenching, which may result in a bias towards jets that have suffered only modest modifications and complicates interpretation of the data [8,9]. Alternatively, the initial parton p_T can be tagged with a particle unaffected by the medium, such as a photon (γ) [10–12]. The photon approximately balances the parton p_T before quenching and, thus, selects populations of jets in pp and Pb + Pb collisions with identical initial conditions. A jet recoiling against a prompt photon is more likely to be initiated by the showering of a light quark, whereas inclusive jets are mostly initiated by gluons. Thus, γ-tagged jets can provide information about how energy loss depends on the color charge of the initiating parton. Finally, the photon selection equally samples all geometric production points, whereas the inclusive selection may be biased towards jets which have lost less energy or were produced near the surface of the medium [13–15].

Many theoretical models of jet quenching have highlighted the value of γ-tagged jet measurements [16–18], inviting systematic comparisons of these with inclusive jet measurements and with theoretical predictions for inclusive and γ-tagged jets. The comparisons are best performed if the measurements are fully corrected for detector effects and presented at particle level. This Letter presents such a measurement of the FF in high-p_T jets azimuthally balanced by a prompt, isolated photon in pp and Pb + Pb collisions at a center-of-mass energy of 5.02 TeV per nucleon pair, using data samples with integrated luminosities of 25 pb^{-1} and 0.49 nb^{-1}, respectively. Photon-hadron p_T correlations in gold-gold collisions were measured at the Relativistic Heavy Ion Collider [19,20]. A measurement of the γ-tagged jet FF at the LHC compared the FF at detector level with theoretical calculations that parametrize the detector smearing effects [21].

Following previous measurements in ATLAS [5,6], the FF for a jet to contain a charged particle with a given p_T, η, and ϕ [22] is expressed as $D(p_T) = (1/N_{\mathrm{jet}})[dN_{\mathrm{ch}}(p_T)/dp_T]$ or $D(z) = (1/N_{\mathrm{jet}})[dN_{\mathrm{ch}}(z)/dz]$ where N_{jet} is the total number of jets, N_{ch} is the number of charged particles associated with a jet, and the longitudinal

*Full author list given at the end of the article.

momentum fraction, z, is defined as $p_T \cos(\Delta R)/p_T^{\text{jet}}$, $\Delta R = [(\eta^{\text{jet}} - \eta^{\text{part}})^2 + (\phi^{\text{jet}} - \phi^{\text{part}})^2]^{1/2}$. Only particles with $\Delta R < 0.4$ are considered.

The principal components of the ATLAS detector [23,24] used in this measurement are the inner tracking detector, electromagnetic and hadronic calorimeters, and an online trigger system. The inner detector is immersed in a 2 T axial magnetic field and provides charged-particle tracking in the range $|\eta| < 2.5$. It consists of a high-granularity silicon pixel detector, a silicon microstrip tracker, and a transition radiation tracker. In the region $|\eta| < 3.2$, electromagnetic calorimetry is provided by barrel and end cap high-granularity lead and liquid-argon (LAr) sections divided into three layers in depth. Hadronic calorimetry is provided by a steel and scintillator-tile calorimeter, segmented into three barrel structures within $|\eta| < 1.7$, and two copper-LAr hadronic end cap calorimeters, covering the region $1.5 < |\eta| < 3.2$. The forward calorimeter is composed of copper-LAr and tungsten-LAr modules and extends the coverage to $|\eta| = 4.9$. During data taking, events with a high transverse energy (E_T^γ) photon are selected using a two-level trigger system based on energy deposition in the electromagnetic calorimeter [25].

Events in Pb + Pb and pp data with photon candidates are selected by the trigger and are required to contain a vertex reconstructed from inner-detector tracks. Two centrality classes of Pb + Pb events are defined using the total transverse energy measured in the forward calorimeter, $\sum E_T$. Central events, which are those with a large nuclear overlap, are defined as those with $\sum E_T$ values in the highest 30% percentile (0%–30%) of all Pb + Pb events. Peripheral events have a $\sum E_T$ value in the 30%–80% percentile and a smaller nuclear overlap region. The mean number of nucleon-nucleon collisions in these events is 1080 ± 70 and 135 ± 9, respectively, evaluated using the Glauber model [26].

Monte Carlo (MC) simulations are used to study the performance of the detector and provide comparisons with data. The main simulation sample was generated with the PYTHIA 8.186 [27] generator, with the NNPDF23LO parton distribution function (PDF) set [28], and parameters tuned to reproduce pp data ("A14" tune) [29]. Events were passed through a full GEANT4 simulation of the detector [30,31], and reconstructed in the same way as the data. Two million pp events were generated, and an additional sample of eight million events were overlaid with Pb + Pb collision data to describe the effects of the underlying event (UE). Additional samples of SHERPA 2.1.1 [32] events using the CT10 PDF [33] and HERWIG 7 [34] events with the MMHT H7UE tune and leading-order PDF set [35], which have a different description of γ+multijet topologies, quark-gluon jet composition, and hadronization, are used to study systematic uncertainties. At particle level, jets and photon isolation energies are defined using stable particles [36].

Photons are measured following a procedure used previously in Pb + Pb collisions [10,11], which includes an event-by-event estimation and subtraction of the UE contribution to the energy deposited in each calorimeter cell [37]. Photon candidates are reconstructed from clusters of energy in the calorimeter and identified using requirements on the properties of their showers [38]. Events with a prompt, isolated photon with E_T^γ in the range 80 to 126 GeV (chosen to match the range used in Ref. [11]) and absolute pseudorapidity smaller than 2.37, excluding the region 1.37–1.56 which has more inactive material, are selected for analysis. The isolation energy, E_T^{iso}, is determined from the sum of the transverse energy in cells inside a cone size of $\Delta R = 0.3$ centered on the photon after subtracting the photon's contribution to this quantity and is required to be $E_T^{\text{iso}} < 3$ GeV (< 10 GeV) in pp (Pb + Pb) collisions.

The combined photon reconstruction and selection efficiencies in pp, peripheral, and central Pb + Pb events are ≈90%, 85%, and 65%–70%, and approximately 10000, 1800, and 6800 photons are selected, respectively. The selected sample contains backgrounds from hadrons and nonisolated photons, called fake photons, that must be removed statistically. The background contribution is determined using a double-sideband approach [10,39,40] in which the identification and isolation requirements are inverted to select background-enriched samples. These are used to estimate the purity of the selection, which is ≈80%–94% depending on the collision system.

Jets are measured following the procedure used previously in pp and Pb + Pb collisions [1,37,41]. The anti-k_t algorithm [42] with $R = 0.4$ is applied to $\Delta\eta \times \Delta\phi = 0.1 \times 0.1$ calorimeter towers. An iterative procedure is used to obtain an event-by-event estimate of the average η-dependent UE energy density, while excluding jets from that estimate. The jet kinematics are corrected for this background and for the detector response using an η- and p_T-dependent calibration derived from simulation and additional small corrections from *in situ* studies [43,44]. Jets are required to have 63 GeV $< p_T^{\text{jet}} <$ 144 GeV and $|\eta^{\text{jet}}| < 2.1$, and be azimuthally balanced with the photon, with separation $|\Delta\phi| > 7\pi/8$. All γ-jet pairs meeting the criteria are included in the analysis, but the requirements mainly select topologies with a single high-p_T balancing jet [11,45]. In simulation, the p_T^{jet} scale is within 1% of unity, while the resolution at $p_T^{\text{jet}} = 63$ GeV is 21% in central Pb + Pb events, 12% in pp events, and improves with increasing p_T^{jet}. Among these jets, 73%–83% are quark jets depending on the generator. The jet flavor is defined by the highest-p_T parton within $\Delta R < 0.4$ of the jet [46].

The jet yield N_{jet} is corrected for the combinatorial pairings of the photon with a jet not associated with the photon-producing hard scattering, and for the contribution of jets paired with fake photons. The first is evaluated in the data-overlay simulation and subtracted on a per-photon basis. The second is subtracted by measuring this yield in the background-dominated sidebands described above and scaling it to match the determined impurity. After these background corrections, the yields are corrected for the effects of bin migration, which are small due to the large p_T^{jet} range of the measurement relative to the resolution.

The FFs $D(z)$ and $D(p_T)$ are measured using the differential yield of charged particles with $p_T > 1$ GeV, N_{ch}, within γ-balancing jets, divided by the total jet yield N_{jet}. This approach was used in previous measurements [5,47] and is needed, together with the unfolding procedure described below, to account for the simultaneous bin migration in the jet and particle kinematic variables, which is correlated through the fragmentation of each jet. Charged-particle tracks are reconstructed from hits in the inner detector using an algorithm that is optimized for the high-occupancy conditions in Pb + Pb collisions [2,6]. They are required to meet several criteria including a minimum number of hits, the presence of hits predicted by the algorithm, and a small distance-of-closest approach to the vertex.

The raw charged-particle yield $N_{\text{ch}}(z)$ or $N_{\text{ch}}(p_T)$ is initially determined by measuring the two-dimensional $(p_T^{\text{jet}},\ p_T)$ or (p_T^{jet}, z) distribution. Each entry is corrected for the tracking efficiency at the given p_T and η, which varies from 60% to 80% depending on occupancy and pseudorapidity. Three background contributions are estimated and are subtracted statistically: (1) UE particles and misreconstructed or secondary tracks, estimated using the rate of tracks not matched to a generated particle in the data-overlay simulation, (2) charged particles in jets not produced in the same hard process as the photon, also estimated in simulation, and (3) the charged-particle yield in jets correlated with fake photons, determined using the sideband approach described above.

The two-dimensional yield is corrected for bin migration along both axes using a Bayesian unfolding procedure [48,49] as in previous dijet and γ-jet measurements [11,50]. The simulated p_T^{jet} distributions are reweighted to match those in data, and the number of unfolding iterations is chosen to minimize the combination of the total statistical uncertainty and residual sensitivity to the assumed prior distribution. Because of the large size of the kinematic bins relative to the experimental resolution, the unfolding changes the yields by typically 5% (10%) in pp (Pb + Pb) collisions. This procedure is further validated with a test performed by dividing the simulated events into statistically independent halves.

The measurement and correction of the p_T^{jet} is affected by uncertainties in the jet energy scale and resolution, which are evaluated following the procedure [44] used in previous ATLAS measurements of heavy-ion collisions. The fake photon background subtraction is sensitive to the determination of the photon purity, which is evaluated as in Ref. [11]. Uncertainties related to the charged-particle yield measurement are described in detail in Ref. [6]. The sensitivity to the unfolding and physics modeling is determined through a pseudoexperiment resampling of the response matrices, varying the prior distributions used in the unfolding, and using the SHERPA simulation instead of PYTHIA8 to perform the unfolding. For uncertainty sources with up or down variations, the changes in the results are averaged to make a symmetric uncertainty. For those with a single variation, an identical uncertainty in the opposite direction is assigned.

Many of these variations change N_{jet} and N_{ch} in a significant but highly correlated way, with the result that the FFs are less sensitive to them. Furthermore, most uncertainties are correlated between the pp and Pb + Pb systems, and these partially cancel out when they are evaluated for the ratios of FFs. The total uncertainties in the $D(z)$ and $D(p_T)$ distributions and their ratios are typically 5% at moderate z or p_T values. At low p_T or z, the track-related uncertainties rise sharply due to the high occupancies in Pb + Pb events. At large p_T or z, where the FF is very steeply falling, the uncertainties related to the choice of prior and physics models dominate.

Figure 1 shows the corrected $D(p_T)$ and $D(z)$ distributions for jets azimuthally balanced by a high-p_T photon in pp events, and in central and peripheral Pb + Pb events. The γ-tagged jet FF in pp collisions is observed to be harder than the FF for inclusive jets at the same collision energy with p_T^{jet} in the range of 80–110 GeV, coinciding with the peak of the γ-tagged p_T^{jet} distribution [47]. This is consistent with the two samples having different quark jet fractions, and with expectations from, e.g., data from the Large Electron-Positron collider [51–53], where harder FFs for quark jets were observed compared with those for gluon jets. The pp data are also compared with generator distributions, which are typically compatible with the data at low to moderate values of z or p_T within uncertainties.

The left and central panels of Fig. 2 summarize ratios of the γ-tagged FFs in Pb + Pb events to those in pp events, and compares them to those for inclusively selected jets with $p_T^{\text{jet}} = 100$–126 GeV measured in 2.76 TeV Pb + Pb and pp collisions [5]. Although the collision energy and p_T^{jet} range are slightly different than that for the γ-tagged jet data, inclusive jet FFs in this region have been observed to be compatible at the two energies and in nearby p_T^{jet} ranges within uncertainties [6]. Since the inclusive-jet measurement uses different centrality ranges, the centrality range corresponding to the top of that in the γ-tagged measurement is chosen (i.e., 0%–10% for 0%–30% in the γ-tagged case, and 30%–40% for 30%–80%). In peripheral collisions, the modification pattern is quantitatively similar for both sets of jets, featuring a depletion at moderate z or p_T, and an enhancement at very low and very high z or p_T.

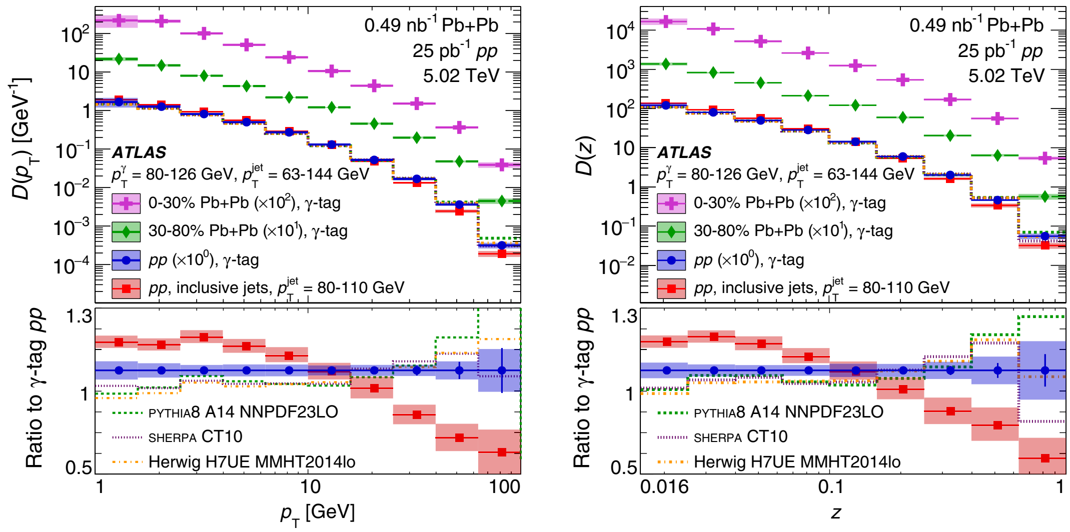

FIG. 1. Fragmentation function (FF) in γ-tagged jets in pp events, and in central and peripheral Pb + Pb events, as a function of charged-particle transverse momentum p_T (left) and longitudinal momentum fraction z (right). The pp results are compared with the analogous distribution in MC generators (dashed lines) and with the FF for inclusive jets in a similar p_T^{jet} range (red squares). The shaded bands correspond to the total systematic uncertainties in the data. The bottom panels show the ratios of MC distributions and inclusive jet data, in pp collisions, to the γ-tagged jet data, with these data plotted at unity.

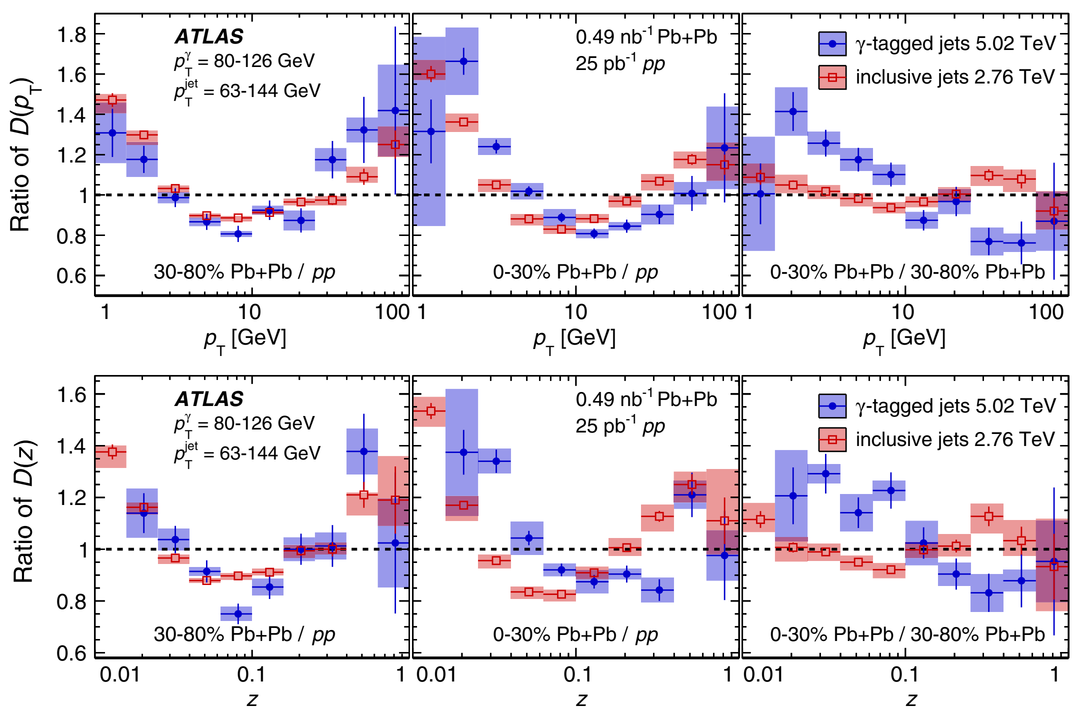

FIG. 2. Ratio of the fragmentation function in jets azimuthally balanced by a high-p_T photon: 30%–80% Pb + Pb collisions to pp collisions (left panels); 0%–30% Pb + Pb collisions to pp collisions (central panels); and 0%–30% to 30%–80% Pb + Pb collisions (right panels). Results are shown as a function of charged-particle transverse momentum p_T (top panels) or longitudinal momentum fraction z (bottom panels), for γ-tagged jets (this measurement, full markers) and for inclusive jets in 2.76 TeV Pb + Pb collisions [5,54] (see text, open markers). The centrality selections for the inclusive jet data are 0%–10% (left), 30%–40% (central), and (0%–10%)/(30%–40%) (right). Hatched bands and vertical bars show for each measurement the total systematic and statistical uncertainties, respectively.

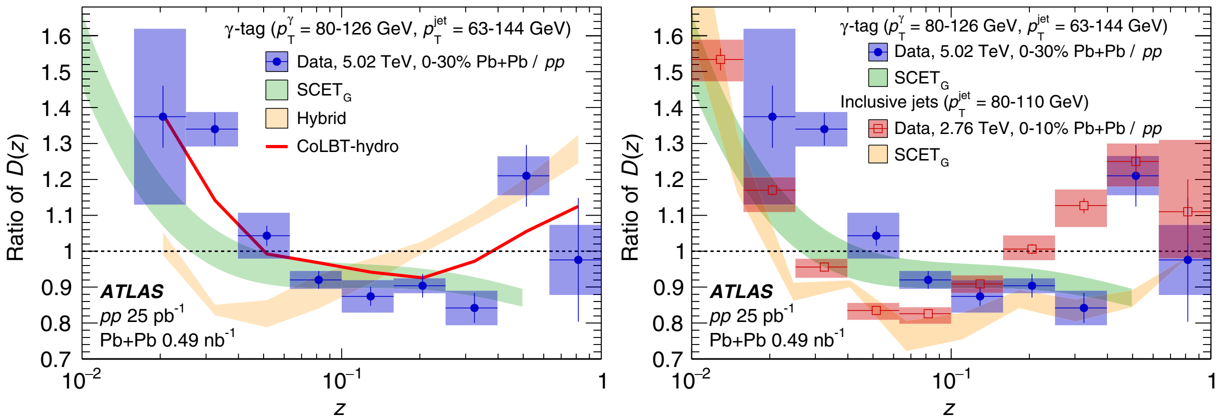

FIG. 3. Comparison of the ratio of γ-tagged fragmentation function $D(z)$ in central Pb + Pb events to pp events with theoretical calculations (left). The mutual comparison between γ-tagged and inclusive jet $D(z)$ ratios in data to each of these in the SCET$_G$ model is shown in the right panel. Shaded rectangles and vertical bars show the total systematic and statistical uncertainties, respectively, in the data.

However, in central collisions, γ-tagged jets show an additional relative suppression at high z or p_T and a counterbalancing enhancement at low z or p_T. In addition, the minimum value of the Pb + Pb-to-pp ratio for γ-tagged jets is shifted to larger z or p_T values.

To further explore the relative change in the FF between Pb + Pb event classes, the ratio between central and peripheral collisions is shown in the right panels of Fig. 2. For γ-tagged jets, the ratio is consistent with a decreasing linear function of $\log(z)$ or $\log(p_T)$, crossing unity at $z \approx 0.1$ or $p_T \approx 10$ GeV. It is inconsistent with the analogous ratio for inclusive jets, which is closer to unity. Thus, the data indicate that, in central collisions, jets in γ-tagged events are modified in a different way than inclusively selected jets.

In Fig. 3, the data in central events are compared with the results of theoretical calculations at particle level. In the left panel, these include: (1) a perturbative calculation within the framework of soft-collinear effective field theory with Glauber gluons (SCET$_\mathrm{G}$) in the soft-gluon-emission (energy-loss) limit, with jet-medium coupling $g = 2.1 \pm 0.1$ [55,56], (2) the hybrid strong and weak coupling model [16], which combines initial production using PYTHIA with a parametrization of energy loss derived from holographic methods, including back reaction effects, and (3) the linearized Boltzmann transport (CoLBT-hydro) model [57] of parton propagation through quark-gluon plasma with jet-induced medium-excitation effects. The SCET$_\mathrm{G}$ calculation and the CoLBT-hydro model successfully capture the key features of the γ-tagged jet FF data in the region $z < 0.5$. In the right panel, the inclusive and γ-tagged FF ratios in data are compared with those in SCET$_\mathrm{G}$. The γ-tagged FF ratio is larger than the inclusive-jet one in the region $z < 0.1$ in both data and theory.

In summary, this Letter presents a measurement of the charged-particle fragmentation functions for jets azimuthally balanced by a high-$p_T T$ prompt and isolated photon. The measurement is performed using 25 pb^{-1} of pp and 0.49 nb^{-1} of Pb + Pb collision data at 5.02 TeV, with the ATLAS detector at the LHC. The kinematic selections result in events with a single leading jet, a large fraction of which are quark jets. In pp collisions, the γ-tagged jet fragmentation functions are systematically harder than those for inclusive jets at similar p_T^{jet}, consistent with the larger expected fraction of quark jets in γ-tagged events. In 30%–80% centrality Pb + Pb events, γ-tagged jets are observed to be modified through interaction with the medium, with an overall pattern consistent with that for inclusive jets. However, jets in γ-tagged events are modified in 0%–30% Pb + Pb events in a manner not observed for inclusive jets. The SCET$_G$ calculation describes this key feature of the data. However, interpreting this observed difference is complicated by the different jet populations in the two cases. In Pb + Pb collisions, the inclusive jet population at fixed p_T^{jet} is biased towards jets which have lost the least amount of energy. In a geometric picture, such a survivor bias selects jets produced only near the surface of the medium. This bias is largely avoided for γ-tagged jets, which can be selected based on the photon kinematics. Thus, they may include jets that are more quenched, on average, than inclusively selected jets, including ones which sample particularly large path lengths.

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[1] ATLAS Collaboration, Measurements of the Nuclear Modification Factor for Jets in Pb + Pb Collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV with the ATLAS Detector, Phys. Rev. Lett. **114**, 072302 (2015).

[2] ATLAS Collaboration, Measurement of charged-particle spectra in Pb + Pb collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV with the ATLAS detector at the LHC, J. High Energy Phys. 09 (2015) 050.

[3] CMS Collaboration, Measurement of inclusive jet cross sections in pp and PbPb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, Phys. Rev. C **96**, 015202 (2017).

[4] ALICE Collaboration, Measurement of charged jet suppression in Pb-Pb collisions at $\sqrt{s_{NN}} = 2.76$ TeV, J. High Energy Phys. 03 (2014) 013.

[5] ATLAS Collaboration, Measurement of jet fragmentation in Pb + Pb and pp collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV with the ATLAS detector at the LHC, Eur. Phys. J. C **77**, 379 (2017).

[6] ATLAS Collaboration, Measurement of jet fragmentation in Pb + Pb and pp collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV with the ATLAS detector, Phys. Rev. C **98**, 024908 (2018).

[7] CMS Collaboration, Measurement of jet fragmentation in PbPb and pp collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV, Phys. Rev. C **90**, 024908 (2014).

[8] J. Casalderrey-Solana, D. C. Gulhan, J. G. Milhano, D. Pablos, and K. Rajagopal, Angular structure of jet quenching within a hybrid strong/weak coupling model, J. High Energy Phys. 03 (2017) 135.

[9] M. Spousta and B. Cole, Interpreting single jet measurements in Pb + Pb collisions at the LHC, Eur. Phys. J. C **76**, 50 (2016).

[10] ATLAS Collaboration, Centrality, rapidity, and transverse momentum dependence of isolated prompt photon production in lead–lead collisions at $\sqrt{s_{\rm NN}} = 2.76$ TeV measured with the ATLAS detector, Phys. Rev. C **93**, 034914 (2016).

[11] ATLAS Collaboration, Measurement of photon-jet transverse momentum correlations in 5.02 TeV Pb + Pb and pp collisions with ATLAS, Phys. Lett. B **789**, 167 (2019).

[12] CMS Collaboration, Study of jet quenching with isolated-photon + jet correlations in PbPb and pp collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV, Phys. Lett. B **785**, 14 (2018).

[13] H. Agakishiev *et al.*, Studies of di-jet survival and surface emission bias in Au + Au collisions via angular correlations with respect to back-to-back leading hadrons, Phys. Rev. C **83**, 061901 (2011).

[14] T. Renk, Biased showers: A common conceptual framework for the interpretation of high-p_T observables in heavy-ion collisions, Phys. Rev. C **88**, 054902 (2013).

[15] J. G. Milhano and K. C. Zapp, Origins of the di-jet asymmetry in heavy ion collisions, Eur. Phys. J. C **76**, 288 (2016).

[16] J. Casalderrey-Solana, D. C. Gulhan, J. G. Milhano, D. Pablos, and K. Rajagopal, Predictions for boson-jet observables and fragmentation function ratios from a hybrid strong/weak coupling model for jet quenching, J. High Energy Phys. 03 (2016) 053.

[17] Z. B. Kang, I. Vitev, and H. Xing, Vector-boson-tagged jet production in heavy ion collisions at energies available at the LHC, Phys. Rev. C **96**, 014912 (2017).

[18] R. Kunnawalkam Elayavalli and K. C. Zapp, Simulating V + jet processes in heavy ion collisions with JEWEL, Eur. Phys. J. C **76**, 695 (2016).

[19] STAR Collaboration, Jet-like correlations with direct-photon and neutral-pion triggers at $\sqrt{s_{NN}} = 200$ GeV, Phys. Lett. B **760**, 689 (2016).

[20] PHENIX Collaboration, Medium Modification of Jet Fragmentation in Au + Au Collisions at $\sqrt{s_{NN}} = 200$ GeV Measured in Direct Photon-Hadron Correlations, Phys. Rev. Lett. **111**, 032301 (2013).

[21] CMS Collaboration, Observation of Medium-Induced Modifications of Jet Fragmentation in Pb-Pb Collisions at $\sqrt{s_{\rm NN}} = 5.02$ TeV Using Isolated Photon-Tagged Jets, Phys. Rev. Lett. **121**, 242301 (2018).

[22] ATLAS uses a right-handed coordinate system with its origin at the nominal interaction point (IP) in the center of the detector and the z axis along the beam pipe. The x axis points from the IP to the center of the LHC ring, and the y axis points upward. Cylindrical coordinates (r, ϕ) are used in the transverse plane, ϕ being the azimuthal angle around the z axis. The pseudorapidity is defined in terms of the polar angle θ as $\eta = -\ln\tan(\theta/2)$. Transverse momentum and transverse energy are defined as $p_T = p\sin\theta$ and $E_T = E\sin\theta$, respectively.

[23] ATLAS Collaboration, The ATLAS experiment at the CERN large hadron collider, J. Instrum. **3**, S08003 (2008).
[24] ATLAS Collaboration, ATLAS insertable B-layer technical design report, CERN Reports No. CERN-LHCC-2010-013 and No. ATLAS-TDR-19, 2010.
[25] ATLAS Collaboration, Performance of the ATLAS trigger system in 2015, Eur. Phys. J. C **77**, 317 (2017).
[26] ATLAS Collaboration, Prompt and non-prompt J/ψ and $\psi(2S)$ suppression at high transverse momentum in 5.02 TeV Pb + Pb collisions with the ATLAS experiment, Eur. Phys. J. C **78**, 762 (2018).
[27] T. Sjöstrand, S. Mrenna, and P. Z. Skands, A brief introduction to PYTHIA 8.1, Comput. Phys. Commun. **178**, 852 (2008).
[28] R. D. Ball *et al.*, Parton distributions with LHC data, Nucl. Phys. **B867**, 244 (2013).
[29] ATLAS Collaboration, ATLAS Pythia 8 tunes to 7 TeV data, CERN Report No. ATL-PHYS-PUB-2014-021, 2014, https://cds.cern.ch/record/1966419.
[30] S. Agostinelli *et al.*, GEANT4—A simulation toolkit, Nucl. Instrum. Methods Phys. Res., Sect. A **506**, 250 (2003).
[31] ATLAS Collaboration, The ATLAS simulation infrastructure, Eur. Phys. J. C **70**, 823 (2010).
[32] T. Gleisberg, S. Höche, F. Krauss, M. Schönherr, S. Schumann, F. Siegert, and J. Winter, Event generation with SHERPA 1.1, J. High Energy Phys. 02 (2009) 007.
[33] H.-L. Lai, M. Guzzi, J. Huston, Z. Li, P. M. Nadolsky, J. Pumplin, and C. P. Yuan, New parton distributions for collider physics, Phys. Rev. D **82**, 074024 (2010).
[34] J. Bellm *et al.*, Herwig 7.0/Herwig++ 3.0 release note, Eur. Phys. J. C **76**, 196 (2016).
[35] L. A. Harland-Lang, A. D. Martin, P. Motylinski, and R. S. Thorne, Parton distributions in the LHC era: MMHT 2014 PDFs, Eur. Phys. J. C **75**, 204 (2015).
[36] Stable particles are defined as those with a proper mean lifetime, τ, exceeding $c\tau = 10$ mm. Muons and neutrinos from decaying hadrons are excluded from the jet clustering.
[37] ATLAS Collaboration, Measurement of the jet radius and transverse momentum dependence of inclusive jet suppression in lead–lead collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with the ATLAS detector, Phys. Lett. B **719**, 220 (2013).
[38] ATLAS Collaboration, Measurement of the photon identification efficiencies with the ATLAS detector using LHC Run 2 data collected in 2015 and 2016, Eur. Phys. J. C **79**, 205 (2019).
[39] ATLAS Collaboration, Measurement of the inclusive isolated prompt photon cross section in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, J. High Energy Phys. 08 (2016) 005.
[40] ATLAS Collaboration, Measurement of the cross section for inclusive isolated-photon production in pp collisions at $\sqrt{s} = 13$ TeV using the ATLAS detector, Phys. Lett. B **770**, 473 (2017).
[41] ATLAS Collaboration, Centrality and rapidity dependence of inclusive jet production in $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV proton-lead collisions with the ATLAS detector, Phys. Lett. B **748**, 392 (2015).
[42] M. Cacciari, G. P. Salam, and G. Soyez, FastJet user manual, Eur. Phys. J. C **72**, 1896 (2012).
[43] ATLAS Collaboration, Jet calibration and systematic uncertainties for jets reconstructed in the ATLAS detector at $\sqrt{s} = 13$ TeV, CERN Report No. ATL-PHYS-PUB-2015-015, 2015, https://cds.cern.ch/record/2037613.
[44] ATLAS Collaboration, Measurement of the nuclear modification factor for inclusive jets in Pb + Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 5.02$ TeV with the ATLAS detector, Phys. Lett. B **790**, 108 (2019).
[45] ATLAS Collaboration, High-E_{T} isolated-photon plus jets production in pp collisions at $\sqrt{s} = 8$ TeV with the ATLAS detector, Nucl. Phys. **B918**, 257 (2017).
[46] ATLAS Collaboration, Jet-proton collisions at $\sqrt{s} = 13$ TeV with the ATLAS detector, Phys. Rev. D **96**, 072002 (2017).
[47] ATLAS Collaboration, Measurement of jet fragmentation in 5.02 TeV proton-lead and proton-proton collisions with the ATLAS detector, Nucl. Phys. **A978**, 65 (2018).
[48] G. D'Agostini, A multidimensional unfolding method based on Bayes' theorem, Nucl. Instrum. Methods Phys. Res., Sect. A **362**, 487 (1995).
[49] T. Adye, Unfolding algorithms and tests using RooUnfold, *Proceedings of the PHYSTAT 2011 Workshop* (CERN, Geneva, 2011).
[50] ATLAS Collaboration, Measurement of jet p_{T} correlations in Pb + Pb and pp collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with the ATLAS detector, Phys. Lett. B **774**, 379 (2017).
[51] OPAL Collaboration, A model independent measurement of quark and gluon jet properties and differences, Z. Phys. C **68**, 179 (1995).
[52] ALEPH Collaboration, Measurements of the structure of quark and gluon jets in hadronic Z decays, Eur. Phys. J. C **17**, 1 (2000).
[53] OPAL Collaboration, Experimental properties of gluon and quark jets from a point source, Eur. Phys. J. C **11**, 217 (1999).
[54] ATLAS Collaboration, Measurement of inclusive jet charged-particle fragmentation functions in Pb + Pb collisions at $\sqrt{s_{\mathrm{NN}}} = 2.76$ TeV with the ATLAS detector, Phys. Lett. B **739**, 320 (2014).
[55] Z.-B. Kang, F. Ringer, and I. Vitev, Inclusive production of small radius jets in heavy-ion collisions, Phys. Lett. B **769**, 242 (2017).
[56] Y.-T. Chien, A. Emerman, Z.-B. Kang, G. Ovanesyan, and I. Vitev, Jet quenching from QCD evolution, Phys. Rev. D **93**, 074030 (2016).
[57] Y. He, T. Luo, X.-N. Wang, and Y. Zhu, Linear Boltzmann transport for jet propagation in the quark-gluon plasma: Elastic processes and medium recoil, Phys. Rev. C **91**, 054908 (2015); Erratum, Phys. Rev. C **97**, 019902(E) (2018).
[58] ATLAS Collaboration, ATLAS computing acknowledgements, CERN Report No. ATL-GEN-PUB-2016-002, 2016, https://cds.cern.ch/record/2202407.

M. Aaboud,[34d] G. Aad,[99] B. Abbott,[125] O. Abdinov,[13,a] B. Abeloos,[129] D. K. Abhayasinghe,[91] S. H. Abidi,[164]
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Soldatov,[110] U. Soldevila,[171] A. A. Solodkov,[121] A. Soloshenko,[77] O. V. Solovyanov,[121] V. Solovyev,[135] P. Sommer,[146] H. Son,[167] W. Song,[141] W. Y. Song,[165b] A. Sopczak,[139] F. Sopkova,[28b] D. Sosa,[59b] C. L. Sotiropoulou,[69a,69b] S. Sottocornola,[68a,68b] R. Soualah,[64a,64c,uu] A. M. Soukharev,[120b,120a] D. South,[44] B. C. Sowden,[91] S. Spagnolo,[65a,65b] M. Spalla,[113] M. Spangenberg,[175] F. Spanò,[91] D. Sperlich,[19] F. Spettel,[113] T. M. Spieker,[59a] R. Spighi,[23b] G. Spigo,[35] L. A. Spiller,[102] D. P. Spiteri,[55] M. Spousta,[140] A. Stabile,[66a,66b] R. Stamen,[59a] S. Stamm,[19] E. Stanecka,[82] R. W. Stanek,[6] C. Stanescu,[72a] B. Stanislaus,[132] M. M. Stanitzki,[44] B. Stapf,[118] S. Stapnes,[131] E. A. Starchenko,[121] G. H. Stark,[36] J. Stark,[56] S. H Stark,[39] P. Staroba,[138] P. Starovoitov,[59a] S. Stärz,[35] R. Staszewski,[82] M. Stegler,[44] P. Steinberg,[29] B. Stelzer,[149] H. J. Stelzer,[35] O. Stelzer-Chilton,[165a] H. Stenzel,[54] T. J. Stevenson,[90] G. A. Stewart,[35] M. C. Stockton,[128] G. Stoicea,[27b] P. Stolte,[51] S. Stonjek,[113] A. Straessner,[46] J. Strandberg,[151] S. Strandberg,[43a,43b] M. Strauss,[125] P. Strizenec,[28b] R. Ströhmer,[174] D. M. Strom,[128] R. Stroynowski,[41] A. Strubig,[48] S. A. Stucci,[29] B. Stugu,[17] J. Stupak,[125] N. A. Styles,[44] D. Su,[150] J. Su,[136] S. Suchek,[59a] Y. Sugaya,[130] M. Suk,[139] V. V. Sulin,[108] D. M. S. Sultan,[52] S. Sultansoy,[4c] T. Sumida,[83] S. Sun,[103] X. Sun,[3] K. Suruliz,[153] C. J. E. Suster,[154] M. R. Sutton,[153] S. Suzuki,[79] M. Svatos,[138] M. Swiatlowski,[36] S. P. Swift,[2] A. Sydorenko,[97] I. Sykora,[28a] T. Sykora,[140] D. Ta,[97] K. Tackmann,[44,vv] J. Taenzer,[158] A. Taffard,[168] R. Tafirout,[165a] E. Tahirovic,[90] N. Taiblum,[158] H. Takai,[29] R. Takashima,[84] E. H. Takasugi,[113] K. Takeda,[80] T. Takeshita,[147] Y. Takubo,[79] M. Talby,[99] A. A. Talyshev,[120b,120a] J. Tanaka,[160] M. Tanaka,[162] R. Tanaka,[129] B. B. Tannenwald,[123] S. Tapia Araya,[144b] S. Tapprogge,[97] A. Tarek Abouelfadl Mohamed,[133] S. Tarem,[157] G. Tarna,[27b,t] G. F. Tartarelli,[66a] P. Tas,[140] M. Tasevsky,[138] T. Tashiro,[83] E. Tassi,[40b,40a] A. Tavares Delgado,[137a,137b] Y. Tayalati,[34e] A. C. Taylor,[116] A. J. Taylor,[48] G. N. Taylor,[102] P. T. E. Taylor,[102] W. Taylor,[165b] A. S. Tee,[87] P. Teixeira-Dias,[91] H. Ten Kate,[35] P. K. Teng,[155] J. J. Teoh,[118] F. Tepel,[179] S. Terada,[79] K. Terashi,[160] J. Terron,[96] S. Terzo,[14] M. Testa,[49] R. J. Teuscher,[164,p] S. J. Thais,[180] T. Theveneaux-Pelzer,[44] F. Thiele,[39]

D. W. Thomas,[91] J. P. Thomas,[21] A. S. Thompson,[55] P. D. Thompson,[21] L. A. Thomsen,[180] E. Thomson,[134] Y. Tian,[38] R. E. Ticse Torres,[51] V. O. Tikhomirov,[108,ww] Yu. A. Tikhonov,[120b,120a] S. Timoshenko,[110] P. Tipton,[180] S. Tisserant,[99] K. Todome,[162] S. Todorova-Nova,[5] S. Todt,[46] J. Tojo,[85] S. Tokár,[28a] K. Tokushuku,[79] E. Tolley,[123] K. G. Tomiwa,[32c] M. Tomoto,[115] L. Tompkins,[150,jj] K. Toms,[116] B. Tong,[57] P. Tornambe,[50] E. Torrence,[128] H. Torres,[46] E. Torró Pastor,[145] C. Tosciri,[132] J. Toth,[99,xx] F. Touchard,[99] D. R. Tovey,[146] C. J. Treado,[122] T. Trefzger,[174] F. Tresoldi,[153] A. Tricoli,[29] I. M. Trigger,[165a] S. Trincaz-Duvoid,[133] M. F. Tripiana,[14] W. Trischuk,[164] B. Trocmé,[56] A. Trofymov,[129] C. Troncon,[66a] M. Trovatelli,[173] F. Trovato,[153] L. Truong,[32b] M. Trzebinski,[82] A. Trzupek,[82] F. Tsai,[44] J. C-L. Tseng,[132] P. V. Tsiareshka,[105] A. Tsirigotis,[159] N. Tsirintanis,[9] V. Tsiskaridze,[152] E. G. Tskhadadze,[156a] I. I. Tsukerman,[109] V. Tsulaia,[18] S. Tsuno,[79] D. Tsybychev,[152] Y. Tu,[61b] A. Tudorache,[27b] V. Tudorache,[27b] T. T. Tulbure,[27a] A. N. Tuna,[57] S. Turchikhin,[77] D. Turgeman,[177] I. Turk Cakir,[4b,yy] R. T. Turra,[66a] P. M. Tuts,[38] E. Tzovara,[97] G. Ucchielli,[23b,23a] I. Ueda,[79] M. Ughetto,[43a,43b] F. Ukegawa,[166] G. Unal,[35] A. Undrus,[29] G. Unel,[168] F. C. Ungaro,[102] Y. Unno,[79] K. Uno,[160] J. Urban,[28b] P. Urquijo,[102] P. Urrejola,[97] G. Usai,[8] J. Usui,[79] L. Vacavant,[99] V. Vacek,[139] B. Vachon,[101] K. O. H. Vadla,[131] A. Vaidya,[92] C. Valderanis,[112] E. Valdes Santurio,[43a,43b] M. Valente,[52] S. Valentinetti,[23b,23a] A. Valero,[171] L. Valéry,[44] R. A. Vallance,[21] A. Vallier,[5] J. A. Valls Ferrer,[171] T. R. Van Daalen,[14] W. Van Den Wollenberg,[118] H. Van der Graaf,[118] P. Van Gemmeren,[6] J. Van Nieuwkoop,[149] I. Van Vulpen,[118] M. Vanadia,[71a,71b] W. Vandelli,[35] A. Vaniachine,[163] P. Vankov,[118] R. Vari,[70a] E. W. Varnes,[7] C. Varni,[53b,53a] T. Varol,[41] D. Varouchas,[129] K. E. Varvell,[154] G. A. Vasquez,[144b] J. G. Vasquez,[180] F. Vazeille,[37] D. Vazquez Furelos,[14] T. Vazquez Schroeder,[101] J. Veatch,[51] V. Vecchio,[72a,72b] L. M. Veloce,[164] F. Veloso,[137a,137c] S. Veneziano,[70a] A. Ventura,[65a,65b] M. Venturi,[173] N. Venturi,[35] V. Vercesi,[68a] M. Verducci,[72a,72b] C. M. Vergel Infante,[76] W. Verkerke,[118] A. T. Vermeulen,[118] J. C. Vermeulen,[118] M. C. Vetterli,[149,f] N. Viaux Maira,[144b] M. Vicente Barreto Pinto,[52] I. Vichou,[170,a] T. Vickey,[146] O. E. Vickey Boeriu,[146] G. H. A. Viehhauser,[132] S. Viel,[18] L. Vigani,[132] M. Villa,[23b,23a] M. Villaplana Perez,[66a,66b] E. Vilucchi,[49] M. G. Vincter,[33] V. B. Vinogradov,[77] A. Vishwakarma,[44] C. Vittori,[23b,23a] I. Vivarelli,[153] S. Vlachos,[10] M. Vogel,[179] P. Vokac,[139] G. Volpi,[14] S. E. von Buddenbrock,[32c] E. Von Toerne,[24] V. 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Weber,[59a] A. R. Weidberg,[132] B. Weinert,[63] J. Weingarten,[45] M. Weirich,[97] C. Weiser,[50] P. S. Wells,[35] T. Wenaus,[29] T. Wengler,[35] S. Wenig,[35] N. Wermes,[24] M. D. Werner,[76] P. Werner,[35] M. Wessels,[59a] T. D. Weston,[20] K. Whalen,[128] N. L. Whallon,[145] A. M. Wharton,[87] A. S. White,[103] A. White,[8] M. J. White,[1] R. White,[144b] D. Whiteson,[168] B. W. Whitmore,[87] F. J. Wickens,[141] W. Wiedenmann,[178] M. Wielers,[141] C. Wiglesworth,[39] L. A. M. Wiik-Fuchs,[50] A. Wildauer,[113] F. Wilk,[98] H. G. Wilkens,[35] L. J. Wilkins,[91] H. H. Williams,[134] S. Williams,[31] C. Willis,[104] S. Willocq,[100] J. A. Wilson,[21] I. Wingerter-Seez,[5] E. Winkels,[153] F. Winklmeier,[128] O. J. Winston,[153] B. T. Winter,[24] M. Wittgen,[150] M. Wobisch,[93] A. Wolf,[97] T. M. H. Wolf,[118] R. Wolff,[99] M. W. Wolter,[82] H. Wolters,[137a,137c] V. W. S. Wong,[172] N. L. Woods,[143] S. D. Worm,[21] B. K. Wosiek,[82] K. W. Woźniak,[82] K. Wraight,[55] M. Wu,[36] S. L. Wu,[178] X. Wu,[52] Y. Wu,[58a] T. R. Wyatt,[98] B. M. Wynne,[48] S. Xella,[39] Z. Xi,[103] L. Xia,[175] D. Xu,[15a] H. Xu,[58a,t] L. Xu,[29] T. Xu,[142] W. Xu,[103] B. Yabsley,[154] S. Yacoob,[32a] K. Yajima,[130] D. P. Yallup,[92] D. Yamaguchi,[162] Y. Yamaguchi,[162] A. Yamamoto,[79] T. Yamanaka,[160] F. Yamane,[80] M. Yamatani,[160] T. Yamazaki,[160] Y. Yamazaki,[80] Z. Yan,[25] H. J. Yang,[58c,58d] H. T. Yang,[18] S. Yang,[75] Y. Yang,[160] Z. Yang,[17] W-M. Yao,[18] Y. C. Yap,[44] Y. Yasu,[79] E. Yatsenko,[58c,58d] J. Ye,[41] S. Ye,[29] I. Yeletskikh,[77] E. Yigitbasi,[25] E. Yildirim,[97] K. Yorita,[176] K. Yoshihara,[134] C. J. S. Young,[35] C. Young,[150] J. Yu,[8] J. Yu,[76] X. Yue,[59a] S. P. Y. Yuen,[24] B. Zabinski,[82] G. Zacharis,[10] E. Zaffaroni,[52] R. Zaidan,[14] A. M. Zaitsev,[121,qq] T. Zakareishvili,[156b] N. Zakharchuk,[44] J. Zalieckas,[17] S. Zambito,[57] D. Zanzi,[35] D. R. Zaripovas,[55] S. V. Zeißner,[45] C. Zeitnitz,[179] G. Zemaityte,[132] J. C. Zeng,[170] Q. Zeng,[150] O. Zenin,[121] D. Zerwas,[129] M. Zgubič,[132] D. F. Zhang,[58b] D. Zhang,[103] F. Zhang,[178] G. Zhang,[58a] H. Zhang,[15c] J. Zhang,[6] L. Zhang,[15c] L. Zhang,[58a] M. Zhang,[170] P. Zhang,[15c] R. Zhang,[58a] R. Zhang,[24] X. Zhang,[58b] Y. Zhang,[15d] Z. Zhang,[129] P. Zhao,[47] X. Zhao,[41] Y. Zhao,[58b,129,cc] Z. Zhao,[58a] A. Zhemchugov,[77] B. Zhou,[103] C. Zhou,[178] L. Zhou,[41] M. S. Zhou,[15d] M. Zhou,[152] N. Zhou,[58c] Y. Zhou,[7] C. G. Zhu,[58b] H. L. Zhu,[58a] H. Zhu,[15a] J. Zhu,[103] Y. Zhu,[58a] X. Zhuang,[15a]

K. Zhukov,[108] V. Zhulanov,[120b,120a] A. Zibell,[174] D. Zieminska,[63] N. I. Zimine,[77] S. Zimmermann,[50] Z. Zinonos,[113] M. Zinser,[97] M. Ziolkowski,[148] G. Zobernig,[178] A. Zoccoli,[23b,23a] K. Zoch,[51] T. G. Zorbas,[146] R. Zou,[36] M. Zur Nedden,[19] and L. Zwalinski[35]

(ATLAS Collaboration)

[1]*Department of Physics, University of Adelaide, Adelaide, Australia*
[2]*Physics Department, SUNY Albany, Albany, New York, USA*
[3]*Department of Physics, University of Alberta, Edmonton, Alberta, Canada*
[4a]*Department of Physics, Ankara University, Ankara, Turkey*
[4b]*Istanbul Aydin University, Istanbul, Turkey*
[4c]*Division of Physics, TOBB University of Economics and Technology, Ankara, Turkey*
[5]*LAPP, Université Grenoble Alpes, Université Savoie Mont Blanc, CNRS/IN2P3, Annecy, France*
[6]*High Energy Physics Division, Argonne National Laboratory, Argonne, Illinois, USA*
[7]*Department of Physics, University of Arizona, Tucson, Arizona, USA*
[8]*Department of Physics, University of Texas at Arlington, Arlington, Texas, USA*
[9]*Physics Department, National and Kapodistrian University of Athens, Athens, Greece*
[10]*Physics Department, National Technical University of Athens, Zografou, Greece*
[11]*Department of Physics, University of Texas at Austin, Austin, Texas, USA*
[12a]*Bahcesehir University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*
[12b]*Istanbul Bilgi University, Faculty of Engineering and Natural Sciences, Istanbul, Turkey*
[12c]*Department of Physics, Bogazici University, Istanbul, Turkey*
[12d]*Department of Physics Engineering, Gaziantep University, Gaziantep, Turkey*
[13]*Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan*
[14]*Institut de Física d'Altes Energies (IFAE), Barcelona Institute of Science and Technology, Barcelona, Spain*
[15a]*Institute of High Energy Physics, Chinese Academy of Sciences, Beijing, China*
[15b]*Physics Department, Tsinghua University, Beijing, China*
[15c]*Department of Physics, Nanjing University, Nanjing, China*
[15d]*University of Chinese Academy of Science (UCAS), Beijing, China*
[16]*Institute of Physics, University of Belgrade, Belgrade, Serbia*
[17]*Department for Physics and Technology, University of Bergen, Bergen, Norway*
[18]*Physics Division, Lawrence Berkeley National Laboratory and University of California, Berkeley, California, USA*
[19]*Institut für Physik, Humboldt Universität zu Berlin, Berlin, Germany*
[20]*Albert Einstein Center for Fundamental Physics and Laboratory for High Energy Physics, University of Bern, Bern, Switzerland*
[21]*School of Physics and Astronomy, University of Birmingham, Birmingham, United Kingdom*
[22]*Facultad de Ciencias y Centro de Investigaciónes, Universidad Antonio Nariño, Bogota, Colombia*
[23a]*INFN Bologna and Universita' di Bologna, Dipartimento di Fisica, Italy*
[23b]*INFN Sezione di Bologna, Italy*
[24]*Physikalisches Institut, Universität Bonn, Bonn, Germany*
[25]*Department of Physics, Boston University, Boston, Massachusetts, USA*
[26]*Department of Physics, Brandeis University, Waltham, Massachusetts, USA*
[27a]*Transilvania University of Brasov, Brasov, Romania*
[27b]*Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania*
[27c]*Department of Physics, Alexandru Ioan Cuza University of Iasi, Iasi, Romania*
[27d]*National Institute for Research and Development of Isotopic and Molecular Technologies, Physics Department, Cluj-Napoca, Romania*
[27e]*University Politehnica Bucharest, Bucharest, Romania*
[27f]*West University in Timisoara, Timisoara, Romania*
[28a]*Faculty of Mathematics, Physics and Informatics, Comenius University, Bratislava, Slovak Republic*
[28b]*Department of Subnuclear Physics, Institute of Experimental Physics of the Slovak Academy of Sciences, Kosice, Slovak Republic*
[29]*Physics Department, Brookhaven National Laboratory, Upton, New York, USA*
[30]*Departamento de Física, Universidad de Buenos Aires, Buenos Aires, Argentina*
[31]*Cavendish Laboratory, University of Cambridge, Cambridge, United Kingdom*
[32a]*Department of Physics, University of Cape Town, Cape Town, South Africa*
[32b]*Department of Mechanical Engineering Science, University of Johannesburg, Johannesburg, South Africa*
[32c]*School of Physics, University of the Witwatersrand, Johannesburg, South Africa*
[33]*Department of Physics, Carleton University, Ottawa, Ontario, Canada*

[34a]*Faculté des Sciences Ain Chock, Réseau Universitaire de Physique des Hautes Energies—Université Hassan II, Casablanca, Morocco*
[34b]*Centre National de l'Energie des Sciences Techniques Nucleaires (CNESTEN), Rabat, Morocco*
[34c]*Faculté des Sciences Semlalia, Université Cadi Ayyad, LPHEA-Marrakech, Morocco*
[34d]*Faculté des Sciences, Université Mohamed Premier and LPTPM, Oujda, Morocco*
[34e]*Faculté des sciences, Université Mohammed V, Rabat, Morocco*
[35]*CERN, Geneva, Switzerland*
[36]*Enrico Fermi Institute, University of Chicago, Chicago, Illinois, USA*
[37]*LPC, Université Clermont Auvergne, CNRS/IN2P3, Clermont-Ferrand, France*
[38]*Nevis Laboratory, Columbia University, Irvington, New York, USA*
[39]*Niels Bohr Institute, University of Copenhagen, Copenhagen, Denmark*
[40a]*Dipartimento di Fisica, Università della Calabria, Rende, Italy*
[40b]*INFN Gruppo Collegato di Cosenza, Laboratori Nazionali di Frascati, Italy*
[41]*Physics Department, Southern Methodist University, Dallas, Texas, USA*
[42]*Physics Department, University of Texas at Dallas, Richardson, Texas, USA*
[43a]*Department of Physics, Stockholm University, Sweden*
[43b]*Oskar Klein Centre, Stockholm, Sweden*
[44]*Deutsches Elektronen-Synchrotron DESY, Hamburg and Zeuthen, Germany*
[45]*Lehrstuhl für Experimentelle Physik IV, Technische Universität Dortmund, Dortmund, Germany*
[46]*Institut für Kern- und Teilchenphysik, Technische Universität Dresden, Dresden, Germany*
[47]*Department of Physics, Duke University, Durham, North Carolina, USA*
[48]*SUPA—School of Physics and Astronomy, University of Edinburgh, Edinburgh, United Kingdom*
[49]*INFN e Laboratori Nazionali di Frascati, Frascati, Italy*
[50]*Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany*
[51]*II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany*
[52]*Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland*
[53a]*Dipartimento di Fisica, Università di Genova, Genova, Italy*
[53b]*INFN Sezione di Genova, Italy*
[54]*II. Physikalisches Institut, Justus-Liebig-Universität Giessen, Giessen, Germany*
[55]*SUPA—School of Physics and Astronomy, University of Glasgow, Glasgow, United Kingdom*
[56]*LPSC, Université Grenoble Alpes, CNRS/IN2P3, Grenoble INP, Grenoble, France*
[57]*Laboratory for Particle Physics and Cosmology, Harvard University, Cambridge, Massachusetts, USA*
[58a]*Department of Modern Physics and State Key Laboratory of Particle Detection and Electronics, University of Science and Technology of China, Hefei, China*
[58b]*Institute of Frontier and Interdisciplinary Science and Key Laboratory of Particle Physics and Particle Irradiation (MOE), Shandong University, Qingdao, China*
[58c]*School of Physics and Astronomy, Shanghai Jiao Tong University, KLPPAC-MoE, SKLPPC, Shanghai, China*
[58d]*Tsung-Dao Lee Institute, Shanghai, China*
[59a]*Kirchhoff-Institut für Physik, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
[59b]*Physikalisches Institut, Ruprecht-Karls-Universität Heidelberg, Heidelberg, Germany*
[60]*Faculty of Applied Information Science, Hiroshima Institute of Technology, Hiroshima, Japan*
[61a]*Department of Physics, Chinese University of Hong Kong, Shatin, N.T., Hong Kong, China*
[61b]*Department of Physics, University of Hong Kong, Hong Kong, China*
[61c]*Department of Physics and Institute for Advanced Study, Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong, China*
[62]*Department of Physics, National Tsing Hua University, Hsinchu, Taiwan*
[63]*Department of Physics, Indiana University, Bloomington, Indiana, USA*
[64a]*INFN Gruppo Collegato di Udine, Sezione di Trieste, Udine, Italy*
[64b]*ICTP, Trieste, Italy*
[64c]*Dipartimento Politecnico di Ingegneria e Architettura, Università di Udine, Udine, Italy*
[65a]*INFN Sezione di Lecce, Italy*
[65b]*Dipartimento di Matematica e Fisica, Università del Salento, Lecce, Italy*
[66a]*INFN Sezione di Milano, Italy*
[66b]*Dipartimento di Fisica, Università di Milano, Milano, Italy*
[67a]*INFN Sezione di Napoli, Italy*
[67b]*Dipartimento di Fisica, Università di Napoli, Napoli, Italy*
[68a]*INFN Sezione di Pavia, Italy*
[68b]*Dipartimento di Fisica, Università di Pavia, Pavia, Italy*
[69a]*INFN Sezione di Pisa, Italy*
[69b]*Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy*

[70a]*INFN Sezione di Roma, Italy*
[70b]*Dipartimento di Fisica, Sapienza Università di Roma, Roma, Italy*
[71a]*INFN Sezione di Roma Tor Vergata, Italy*
[71b]*Dipartimento di Fisica, Università di Roma Tor Vergata, Roma, Italy*
[72a]*INFN Sezione di Roma Tre, Italy*
[72b]*Dipartimento di Matematica e Fisica, Università Roma Tre, Roma, Italy*
[73a]*INFN-TIFPA, Italy*
[73b]*Università degli Studi di Trento, Trento, Italy*
[74]*Institut für Astro- und Teilchenphysik, Leopold-Franzens-Universität, Innsbruck, Austria*
[75]*University of Iowa, Iowa City, Iowa, USA*
[76]*Department of Physics and Astronomy, Iowa State University, Ames, Iowa, USA*
[77]*Joint Institute for Nuclear Research, Dubna, Russia*
[78a]*Departamento de Engenharia Elétrica, Universidade Federal de Juiz de Fora (UFJF), Juiz de Fora, Brazil*
[78b]*Universidade Federal do Rio De Janeiro COPPE/EE/IF, Rio de Janeiro, Brazil*
[78c]*Universidade Federal de São João del Rei (UFSJ), São João del Rei, Brazil*
[78d]*Instituto de Física, Universidade de São Paulo, São Paulo, Brazil*
[79]*KEK, High Energy Accelerator Research Organization, Tsukuba, Japan*
[80]*Graduate School of Science, Kobe University, Kobe, Japan*
[81a]*AGH University of Science and Technology, Faculty of Physics and Applied Computer Science, Krakow, Poland*
[81b]*Marian Smoluchowski Institute of Physics, Jagiellonian University, Krakow, Poland*
[82]*Institute of Nuclear Physics Polish Academy of Sciences, Krakow, Poland*
[83]*Faculty of Science, Kyoto University, Kyoto, Japan*
[84]*Kyoto University of Education, Kyoto, Japan*
[85]*Research Center for Advanced Particle Physics and Department of Physics, Kyushu University, Fukuoka, Japan*
[86]*Instituto de Física La Plata, Universidad Nacional de La Plata and CONICET, La Plata, Argentina*
[87]*Physics Department, Lancaster University, Lancaster, United Kingdom*
[88]*Oliver Lodge Laboratory, University of Liverpool, Liverpool, United Kingdom*
[89]*Department of Experimental Particle Physics, Jožef Stefan Institute and Department of Physics, University of Ljubljana, Ljubljana, Slovenia*
[90]*School of Physics and Astronomy, Queen Mary University of London, London, United Kingdom*
[91]*Department of Physics, Royal Holloway University of London, Egham, United Kingdom*
[92]*Department of Physics and Astronomy, University College London, London, United Kingdom*
[93]*Louisiana Tech University, Ruston, Louisiana, USA*
[94]*Fysiska institutionen, Lunds universitet, Lund, Sweden*
[95]*Centre de Calcul de l'Institut National de Physique Nucléaire et de Physique des Particules (IN2P3), Villeurbanne, France*
[96]*Departamento de Física Teorica C-15 and CIAFF, Universidad Autónoma de Madrid, Madrid, Spain*
[97]*Institut für Physik, Universität Mainz, Mainz, Germany*
[98]*School of Physics and Astronomy, University of Manchester, Manchester, United Kingdom*
[99]*CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France*
[100]*Department of Physics, University of Massachusetts, Amherst, Massachusetts, USA*
[101]*Department of Physics, McGill University, Montreal, Quebec, Canada*
[102]*School of Physics, University of Melbourne, Victoria, Australia*
[103]*Department of Physics, University of Michigan, Ann Arbor, Michigan, USA*
[104]*Department of Physics and Astronomy, Michigan State University, East Lansing, Michigan, USA*
[105]*B.I. Stepanov Institute of Physics, National Academy of Sciences of Belarus, Minsk, Belarus*
[106]*Research Institute for Nuclear Problems of Byelorussian State University, Minsk, Belarus*
[107]*Group of Particle Physics, University of Montreal, Montreal, Quebec, Canada*
[108]*P.N. Lebedev Physical Institute of the Russian Academy of Sciences, Moscow, Russia*
[109]*Institute for Theoretical and Experimental Physics of the National Research Centre Kurchatov Institute, Moscow, Russia*
[110]*National Research Nuclear University MEPhI, Moscow, Russia*
[111]*D.V. Skobeltsyn Institute of Nuclear Physics, M.V. Lomonosov Moscow State University, Moscow, Russia*
[112]*Fakultät für Physik, Ludwig-Maximilians-Universität München, München, Germany*
[113]*Max-Planck-Institut für Physik (Werner-Heisenberg-Institut), München, Germany*
[114]*Nagasaki Institute of Applied Science, Nagasaki, Japan*
[115]*Graduate School of Science and Kobayashi-Maskawa Institute, Nagoya University, Nagoya, Japan*
[116]*Department of Physics and Astronomy, University of New Mexico, Albuquerque, New Mexico, USA*
[117]*Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands*
[118]*Nikhef National Institute for Subatomic Physics and University of Amsterdam, Amsterdam, Netherlands*
[119]*Department of Physics, Northern Illinois University, DeKalb, Illinois, USA*
[120a]*Budker Institute of Nuclear Physics and NSU, SB RAS, Novosibirsk, Russia*

[120b]Novosibirsk State University Novosibirsk, Russia
[121]Institute for High Energy Physics of the National Research Centre Kurchatov Institute, Protvino, Russia
[122]Department of Physics, New York University, New York, New York, USA
[123]The Ohio State University, Columbus, Ohio, USA
[124]Faculty of Science, Okayama University, Okayama, Japan
[125]Homer L. Dodge Department of Physics and Astronomy, University of Oklahoma, Norman, Oklahoma, USA
[126]Department of Physics, Oklahoma State University, Stillwater, Oklahoma, USA
[127]Palacký University, RCPTM, Joint Laboratory of Optics, Olomouc, Czech Republic
[128]Center for High Energy Physics, University of Oregon, Eugene, Oregon, USA
[129]LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France
[130]Graduate School of Science, Osaka University, Osaka, Japan
[131]Department of Physics, University of Oslo, Oslo, Norway
[132]Department of Physics, Oxford University, Oxford, United Kingdom
[133]LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France
[134]Department of Physics, University of Pennsylvania, Philadelphia, Pennsylvania, USA
[135]Konstantinov Nuclear Physics Institute of National Research Centre "Kurchatov Institute", PNPI, St. Petersburg, Russia
[136]Department of Physics and Astronomy, University of Pittsburgh, Pittsburgh, Pennsylvania, USA
[137a]Laboratório de Instrumentação e Física Experimental de Partículas—LIP, Portugal
[137b]Departamento de Física, Faculdade de Ciências, Universidade de Lisboa, Lisboa, Portugal
[137c]Departamento de Física, Universidade de Coimbra, Coimbra, Portugal
[137d]Centro de Física Nuclear da Universidade de Lisboa, Lisboa, Portugal
[137e]Departamento de Física, Universidade do Minho, Braga, Portugal
[137f]Universidad de Granada, Granada (Spain), Spain
[137g]Dep Física and CEFITEC of Faculdade de Ciências e Tecnologia, Universidade Nova de Lisboa, Caparica, Portugal
[138]Institute of Physics of the Czech Academy of Sciences, Prague, Czech Republic
[139]Czech Technical University in Prague, Prague, Czech Republic
[140]Charles University, Faculty of Mathematics and Physics, Prague, Czech Republic
[141]Particle Physics Department, Rutherford Appleton Laboratory, Didcot, United Kingdom
[142]IRFU, CEA, Université Paris-Saclay, Gif-sur-Yvette, France
[143]Santa Cruz Institute for Particle Physics, University of California Santa Cruz, Santa Cruz, California, USA
[144a]Departamento de Física, Pontificia Universidad Católica de Chile, Santiago, Chile
[144b]Departamento de Física, Universidad Técnica Federico Santa María, Valparaíso, Chile
[145]Department of Physics, University of Washington, Seattle, Washington, USA
[146]Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom
[147]Department of Physics, Shinshu University, Nagano, Japan
[148]Department Physik, Universität Siegen, Siegen, Germany
[149]Department of Physics, Simon Fraser University, Burnaby, British Columbia, Canada
[150]SLAC National Accelerator Laboratory, Stanford, California, USA
[151]Physics Department, Royal Institute of Technology, Stockholm, Sweden
[152]Departments of Physics and Astronomy, Stony Brook University, Stony Brook, New York, USA
[153]Department of Physics and Astronomy, University of Sussex, Brighton, United Kingdom
[154]School of Physics, University of Sydney, Sydney, Australia
[155]Institute of Physics, Academia Sinica, Taipei, Taiwan
[156a]E. Andronikashvili Institute of Physics, Iv. Javakhishvili Tbilisi State University, Tbilisi, Georgia
[156b]High Energy Physics Institute, Tbilisi State University, Tbilisi, Georgia
[157]Department of Physics, Technion, Israel Institute of Technology, Haifa, Israel
[158]Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Tel Aviv, Israel
[159]Department of Physics, Aristotle University of Thessaloniki, Thessaloniki, Greece
[160]International Center for Elementary Particle Physics and Department of Physics, University of Tokyo, Tokyo, Japan
[161]Graduate School of Science and Technology, Tokyo Metropolitan University, Tokyo, Japan
[162]Department of Physics, Tokyo Institute of Technology, Tokyo, Japan
[163]Tomsk State University, Tomsk, Russia
[164]Department of Physics, University of Toronto, Toronto, Ontario, Canada
[165a]TRIUMF, Vancouver, British Columbia, Canada
[165b]Department of Physics and Astronomy, York University, Toronto, Ontario, Canada
[166]Division of Physics and Tomonaga Center for the History of the Universe, Faculty of Pure and Applied Sciences, University of Tsukuba, Tsukuba, Japan
[167]Department of Physics and Astronomy, Tufts University, Medford, Massachusetts, USA
[168]Department of Physics and Astronomy, University of California Irvine, Irvine, California, USA
[169]Department of Physics and Astronomy, University of Uppsala, Uppsala, Sweden

[170]*Department of Physics, University of Illinois, Urbana, Illinois, USA*
[171]*Instituto de Física Corpuscular (IFIC), Centro Mixto Universidad de Valencia—CSIC, Valencia, Spain*
[172]*Department of Physics, University of British Columbia, Vancouver, British Columbia, Canada*
[173]*Department of Physics and Astronomy, University of Victoria, Victoria, British Columbia, Canada*
[174]*Fakultät für Physik und Astronomie, Julius-Maximilians-Universität Würzburg, Würzburg, Germany*
[175]*Department of Physics, University of Warwick, Coventry, United Kingdom*
[176]*Waseda University, Tokyo, Japan*
[177]*Department of Particle Physics, Weizmann Institute of Science, Rehovot, Israel*
[178]*Department of Physics, University of Wisconsin, Madison, Wisconsin, USA*
[179]*Fakultät für Mathematik und Naturwissenschaften, Fachgruppe Physik, Bergische Universität Wuppertal, Wuppertal, Germany*
[180]*Department of Physics, Yale University, New Haven, Connecticut, USA*
[181]*Yerevan Physics Institute, Yerevan, Armenia*

[a]Deceased.
[b]Also at Department of Physics, King's College London, London, United Kingdom.
[c]Also at Istanbul University, Department of Physics, Istanbul, Turkey.
[d]Also at Instituto de Física Teórica de la Universidad Autónoma de Madrid, Spain.
[e]Also at Institute of Physics, Azerbaijan Academy of Sciences, Baku, Azerbaijan.
[f]Also at TRIUMF, Vancouver, British Columbia, Canada.
[g]Also at Department of Physics and Astronomy, University of Louisville, Louisville, Kentucky, USA.
[h]Also at Department of Physics, California State University, Fresno, California, USA.
[i]Also at Department of Physics, University of Fribourg, Fribourg, Switzerland.
[j]Also at Physics Department, University of South Africa, Pretoria, South Africa.
[k]Also at Departament de Fisica de la Universitat Autonoma de Barcelona, Barcelona, Spain.
[l]Also at Tomsk State University, Tomsk, and Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
[m]Also at The Collaborative Innovation Center of Quantum Matter (CICQM), Beijing, China.
[n]Also at Departamento de Física, Instituto Superior Técnico, Universidade de Lisboa, Lisboa, Portugal.
[o]Also at Universita di Napoli Parthenope, Napoli, Italy.
[p]Also at Institute of Particle Physics (IPP), Canada.
[q]Also at II. Physikalisches Institut, Georg-August-Universität Göttingen, Göttingen, Germany.
[r]Also at Dipartimento di Fisica E. Fermi, Università di Pisa, Pisa, Italy.
[s]Also at Horia Hulubei National Institute of Physics and Nuclear Engineering, Bucharest, Romania.
[t]Also at CPPM, Aix-Marseille Université, CNRS/IN2P3, Marseille, France.
[u]Also at Department of Physics, St. Petersburg State Polytechnical University, St. Petersburg, Russia.
[v]Also at Borough of Manhattan Community College, City University of New York, New York, USA.
[w]Also at Department of Financial and Management Engineering, University of the Aegean, Chios, Greece.
[x]Also at Centre for High Performance Computing, CSIR Campus, Rosebank, Cape Town, South Africa.
[y]Also at Louisiana Tech University, Ruston, Louisiana, USA.
[z]Also at California State University, East Bay, USA.
[aa]Also at Institucio Catalana de Recerca i Estudis Avancats, ICREA, Barcelona, Spain.
[bb]Also at Department of Physics, University of Michigan, Ann Arbor, Michigan, USA.
[cc]Also at LAL, Université Paris-Sud, CNRS/IN2P3, Université Paris-Saclay, Orsay, France.
[dd]Also at Graduate School of Science, Osaka University, Osaka, Japan.
[ee]Also at Physikalisches Institut, Albert-Ludwigs-Universität Freiburg, Freiburg, Germany.
[ff]Also at Institute for Mathematics, Astrophysics and Particle Physics, Radboud University Nijmegen/Nikhef, Nijmegen, Netherlands.
[gg]Also at Near East University, Nicosia, North Cyprus, Mersin, Turkey.
[hh]Also at Institute of Theoretical Physics, Ilia State University, Tbilisi, Georgia.
[ii]Also at CERN, Geneva, Switzerland.
[jj]Also at Department of Physics, Stanford University, USA.
[kk]Also at Manhattan College, New York, New York, USA.
[ll]Also at Hellenic Open University, Patras, Greece.
[mm]Also at LPNHE, Sorbonne Université, Paris Diderot Sorbonne Paris Cité, CNRS/IN2P3, Paris, France.
[nn]Also at The City College of New York, New York, New York, USA.
[oo]Also at Universidad de Granada, Granada (Spain), Spain.
[pp]Also at Department of Physics, California State University, Sacramento, California, USA.
[qq]Also at Moscow Institute of Physics and Technology State University, Dolgoprudny, Russia.
[rr]Also at Département de Physique Nucléaire et Corpusculaire, Université de Genève, Genève, Switzerland.
[ss]Also at Department of Physics and Astronomy, University of Sheffield, Sheffield, United Kingdom.
[tt]Also at School of Physics, Sun Yat-sen University, Guangzhou, China.

[uu]Also at Department of Applied Physics and Astronomy, University of Sharjah, Sharjah, United Arab Emirates.
[vv]Also at Institut für Experimentalphysik, Universität Hamburg, Hamburg, Germany.
[ww]Also at National Research Nuclear University MEPhI, Moscow, Russia.
[xx]Also at Institute for Particle and Nuclear Physics, Wigner Research Centre for Physics, Budapest, Hungary.
[yy]Also at Giresun University, Faculty of Engineering, Giresun, Turkey.
[zz]Also at Institute of Physics, Academia Sinica, Taipei, Taiwan.